Model for Prediction Across Scales: Status and Outlook

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MPAS

Model for Prediction Across Scales

1. MPAS is an unstructured-grid approach to climate system modeling.

2. MPAS supports both quasi-uniform and variable resolution meshing of the sphere using quadrilaterals, triangles or Voronoi tessellations.

3. MPAS is a software framework for the rapid prototyping of single-components of climate system models (atmosphere, ocean, land ice, etc.).

4. MPAS offers the potential to explore regional-scale climate change within the context of global climate system modeling.

5. MPAS is currently structured as a partnership between NCAR MMM and LANL COSIM, where we intend to distribute our models through open-source, 3rd-party facilities (e.g. Sourceforge).
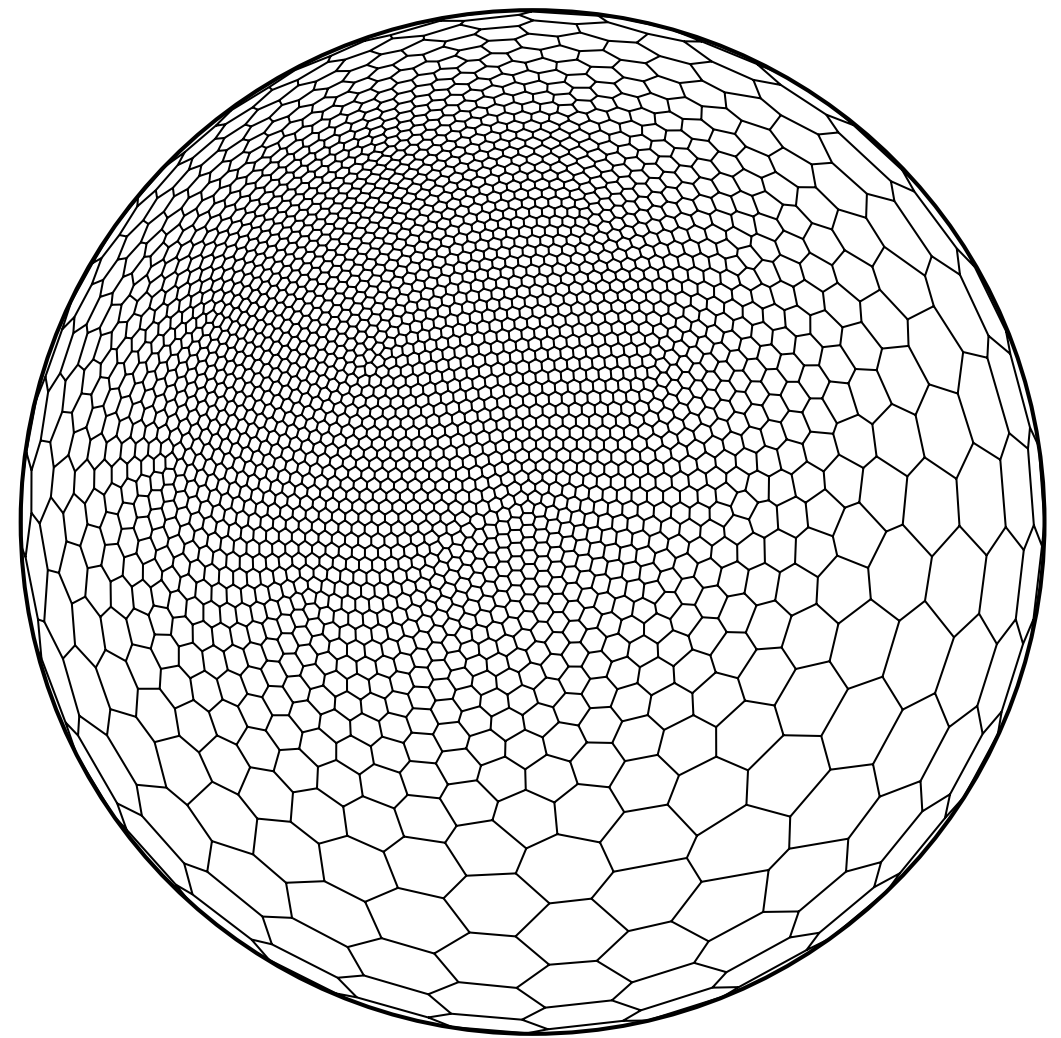
MPAS highlights from the last six months ....

Atmosphere
1. Hydrostatic atmosphere implemented in NCAR/DOE CAM (NCAR, LLNL, LANL)
2. Conducted uniform resolution (120km, 60km) aqua-planet simulations (LLNL, LANL)
3. Conducted variable resolution (40km/120km) aqua-planet simulations (LLNL, LANL)
4. Non-hydrostatic atmosphere working and undergoing testing (NCAR)

Ocean
1. Obtained POP results when using POP stretched grid in MPAS (Petersen)
2. Conducted global simulations with real topography using POP stretched grid (Petersen)
3. Conducted global simulations with real topography using quasi-uniform SCVTs
4. Conducted global simulations with real topography using SCVTs with local refinement
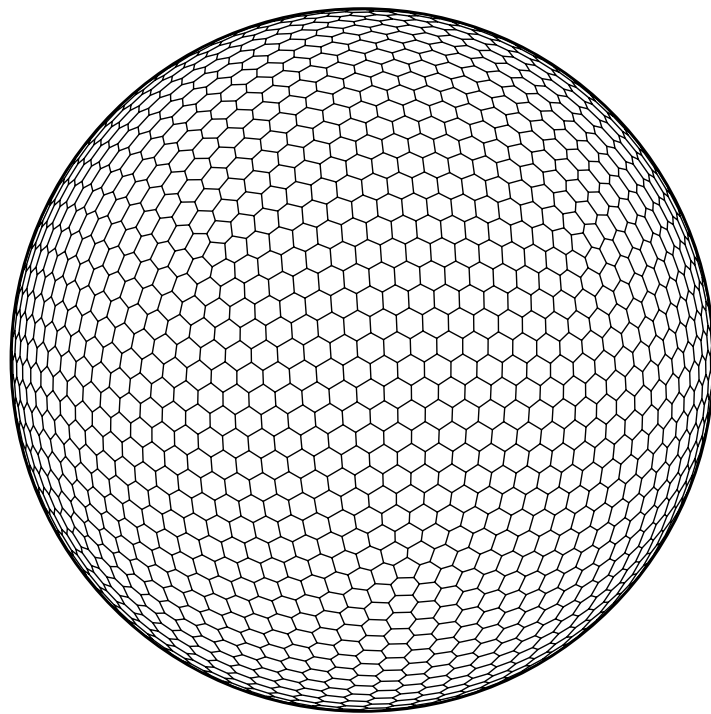5. Prototyped barotopic/baroclinic model splitting algorithm (Newman)

Land Ice
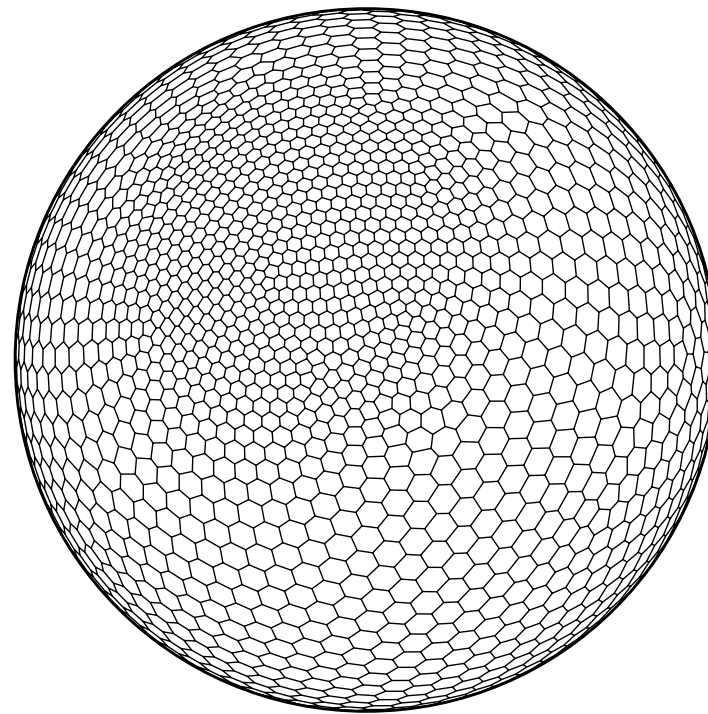1. Began prototyping a MPAS land-ice model

New Funding (to supplement on-going core COSIM support)
1. Development of Frameworks for Robust Regional Climate Modeling
   Leung (PNNL), Ringler (LANL), Collins (LBNL) and Bader (ORNL)
2. Development of a Next-Generation Approach to Regional Climate Prediction at High Resolution
   Holland (NCAR), Barth (NCAR), Skamarock (NCAR), Kunreuther (UPenn), Ringler (LANL), Hakim (Washington)
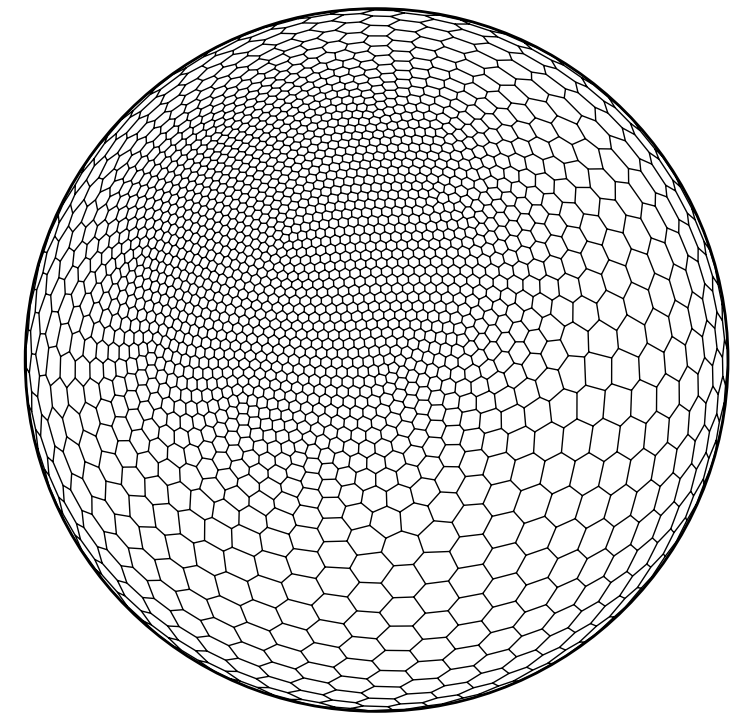
We have started to evaluate the MPAS variable-resolution approach.
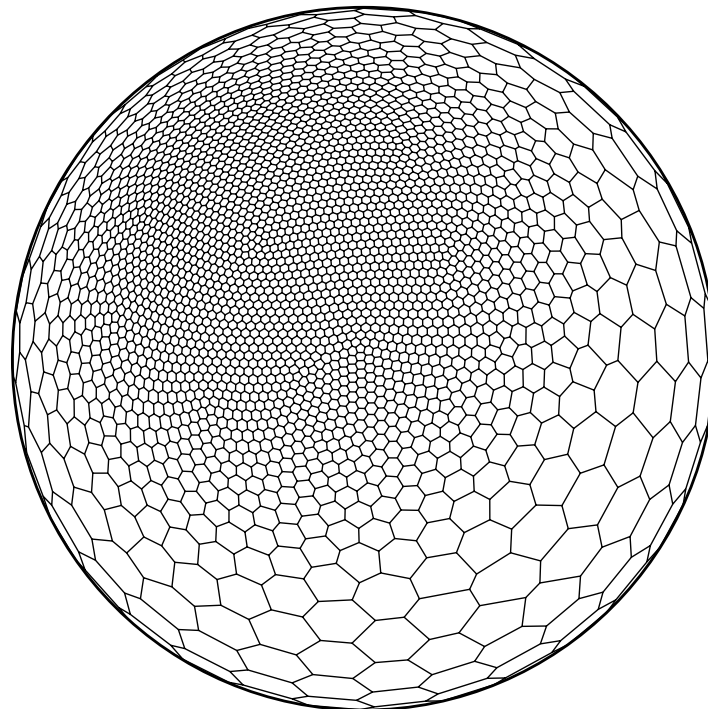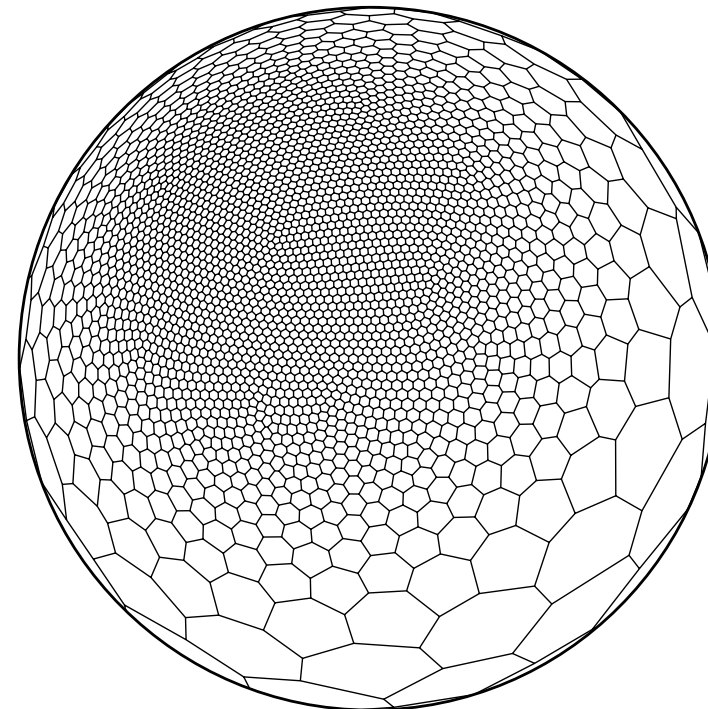## (these are Spherical Centroidal Voronoi Tessellations)

x1

x2

x4

x8

x16

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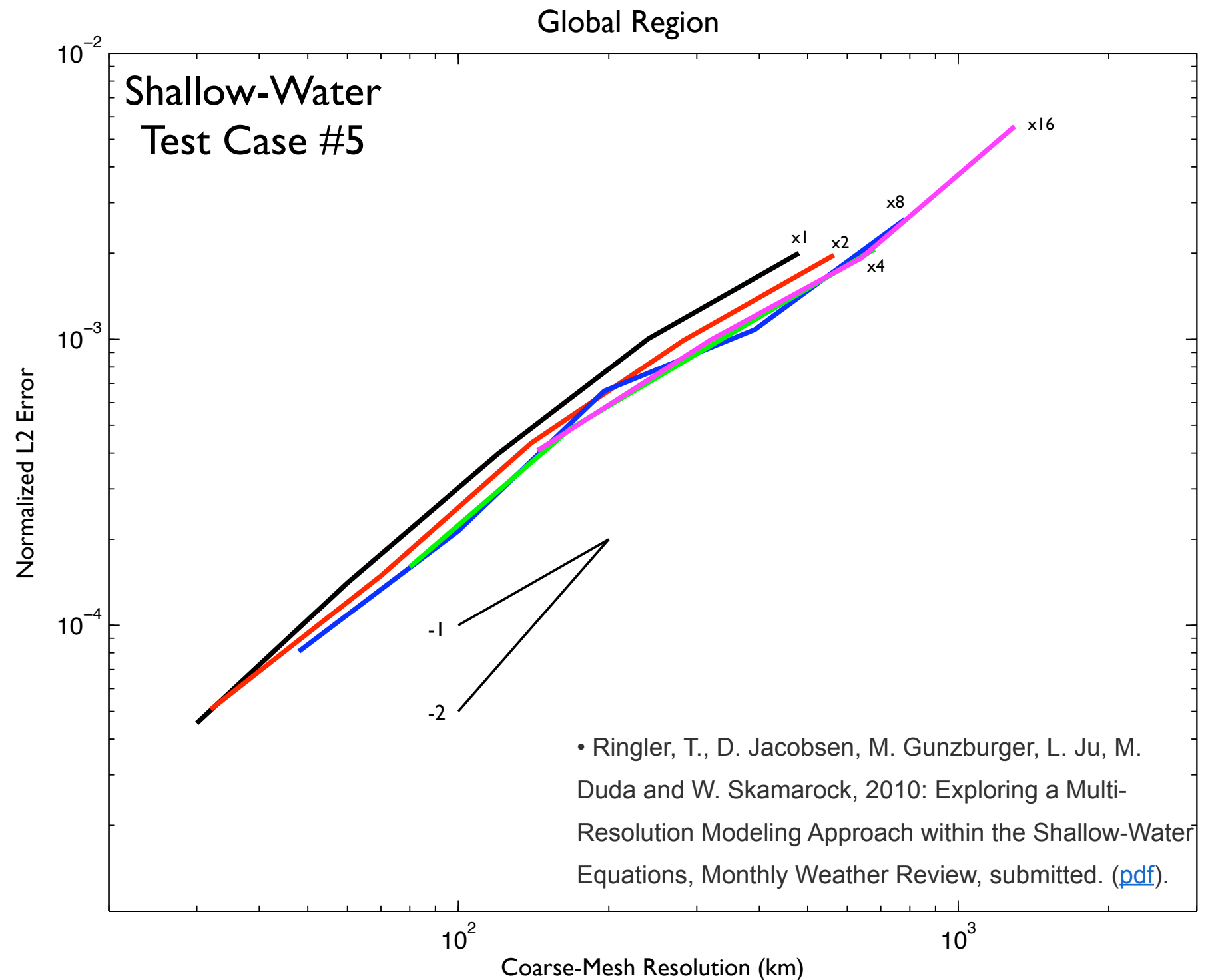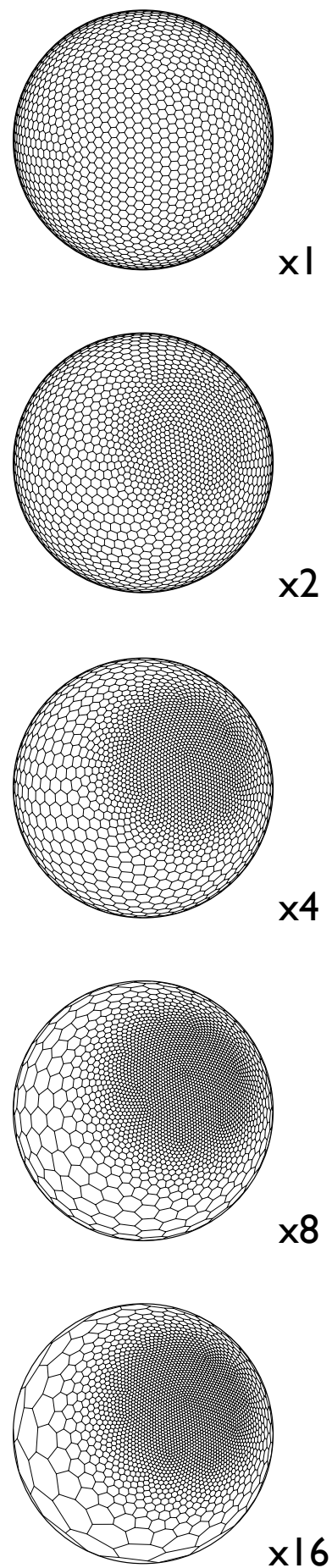NATIONAL LABORATORY
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This evaluation has led us to the following tentative conclusion: We can increase resolution locally without increasing the global solution error.

x1

x2

x4

x8

x16

Global Region

Shallow-Water
Test Case #5

Normalized L2 Error

Coarse-Mesh Resolution (km)

x1   x2
x8   x16
x4

-1

-2

• Ringler, T., D. Jacobsen, M. Gunzburger, L. Ju, M. Duda and W. Skamarock, 2010: Exploring a Multi-Resolution Modeling Approach within the Shallow-Water Equations, Monthly Weather Review, submitted. (pdf).

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In collaboration with our colleagues at LLNL and NCAR, we have started our first multi-resolution aqua-planet simulations.

These simulations are being conducted within the CESM/CAM modeling system and use the standard CAM physics packages.

We will evaluate different levels of refinement, with particular attention toward tropical dynamics.

We intend to present a full analysis at the AMWG meeting in February.
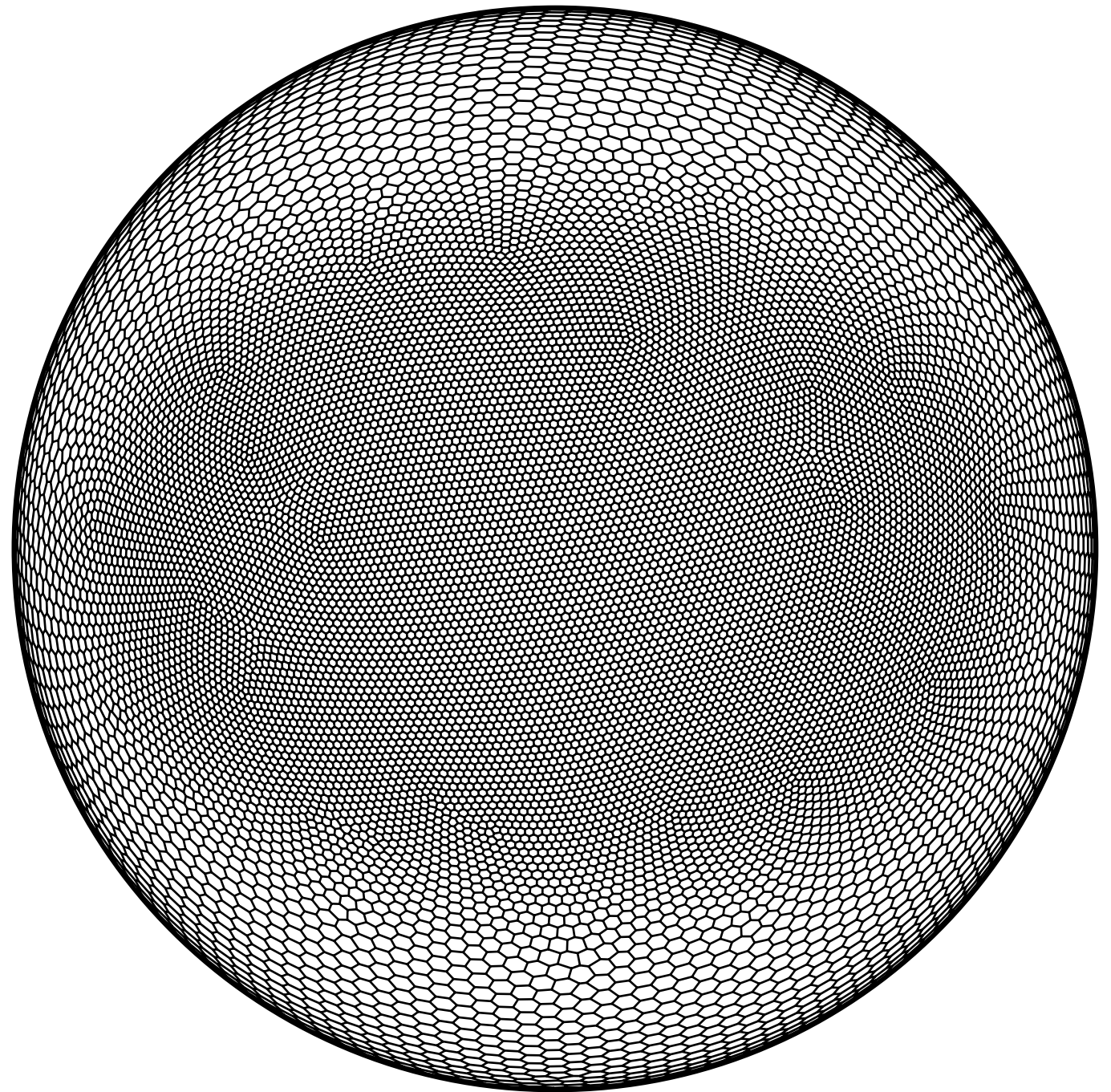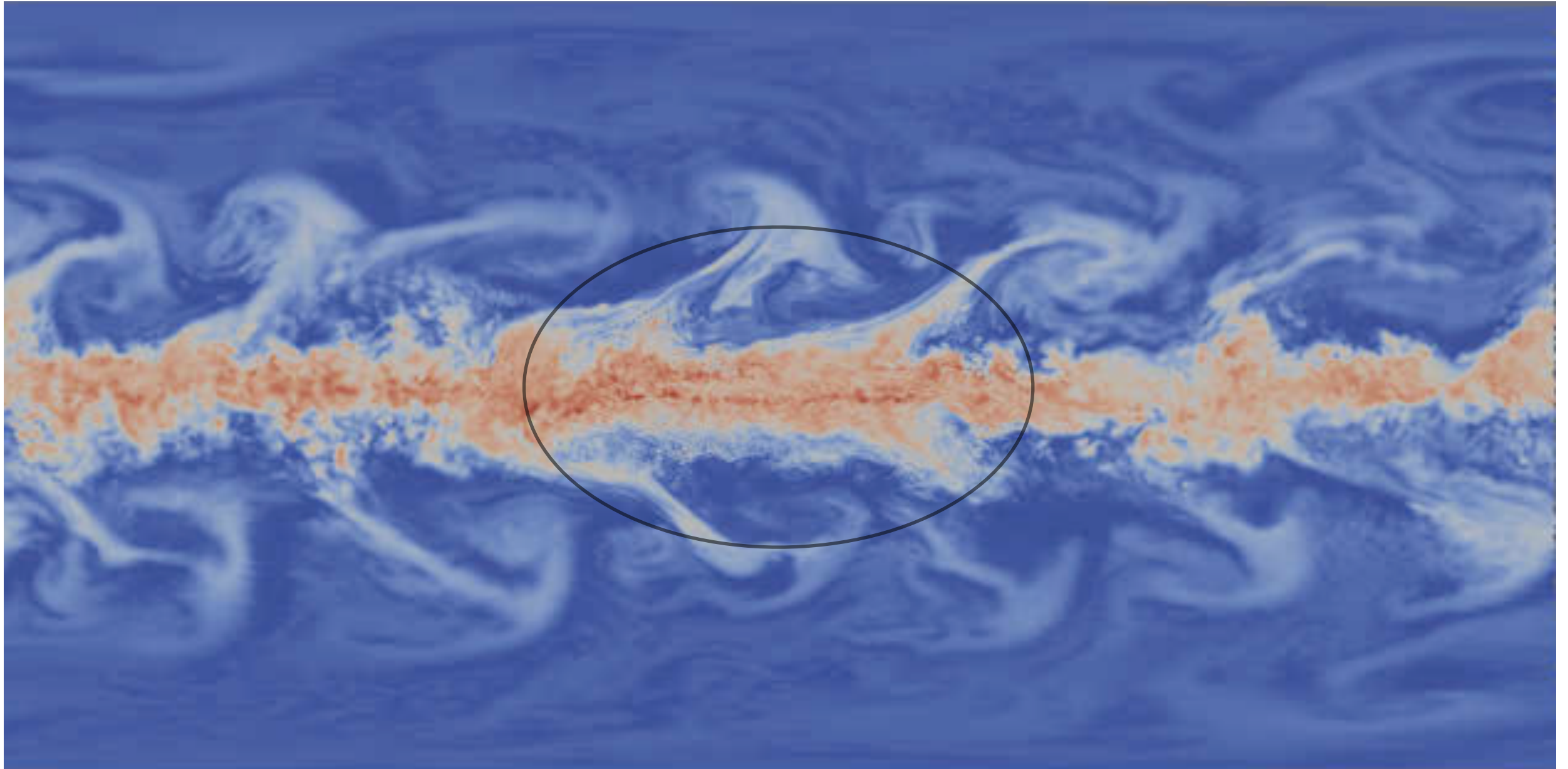
We have completed an aqua-planet simulation using this mesh, but at higher resolution. See next slide.
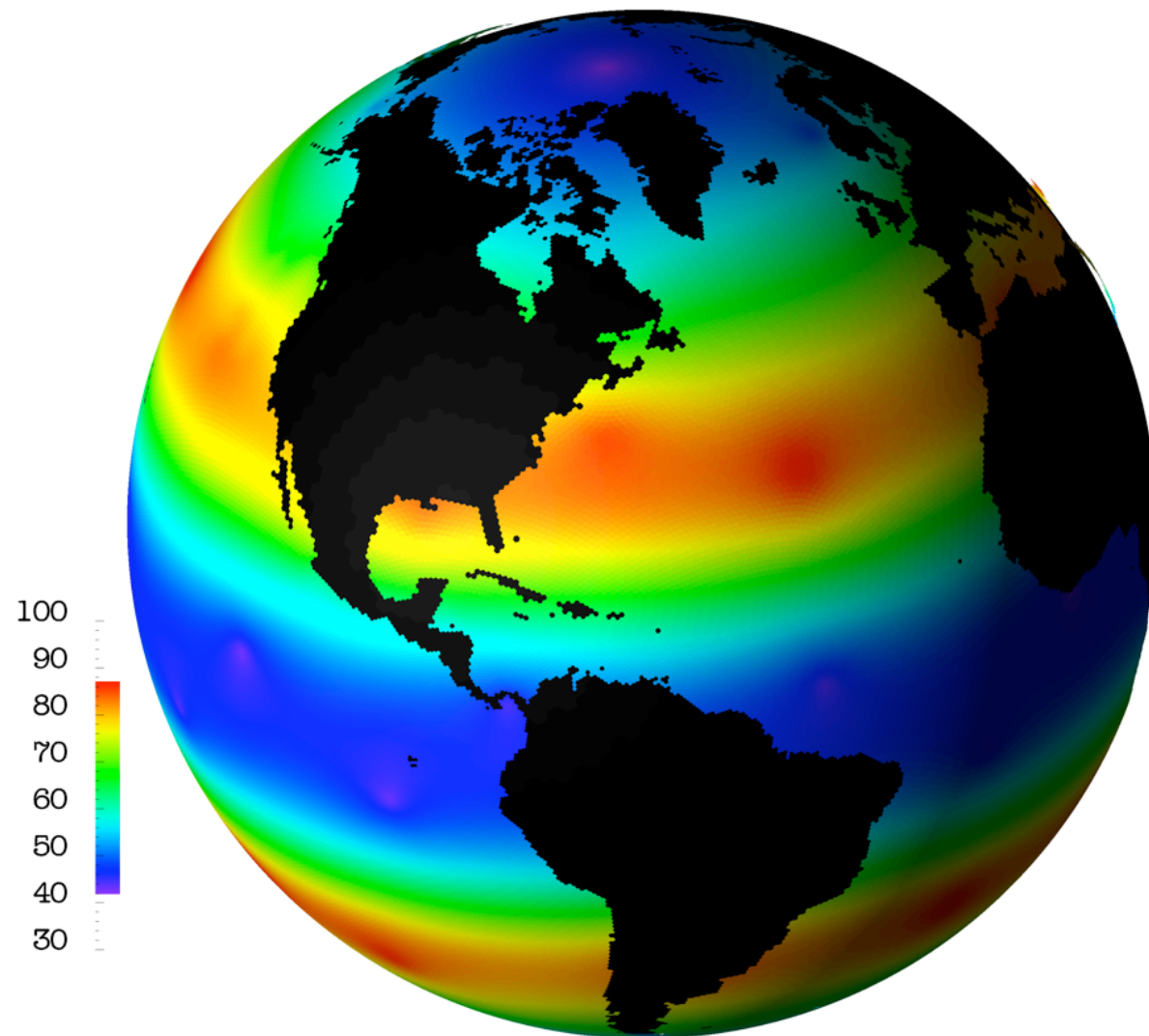
Aqua Planet Simulation
fine resolution: 40 km, coarse resolution: 120 km
full physics, CAM 4

Water Vapor, Level 5, snap shot at end of month 15
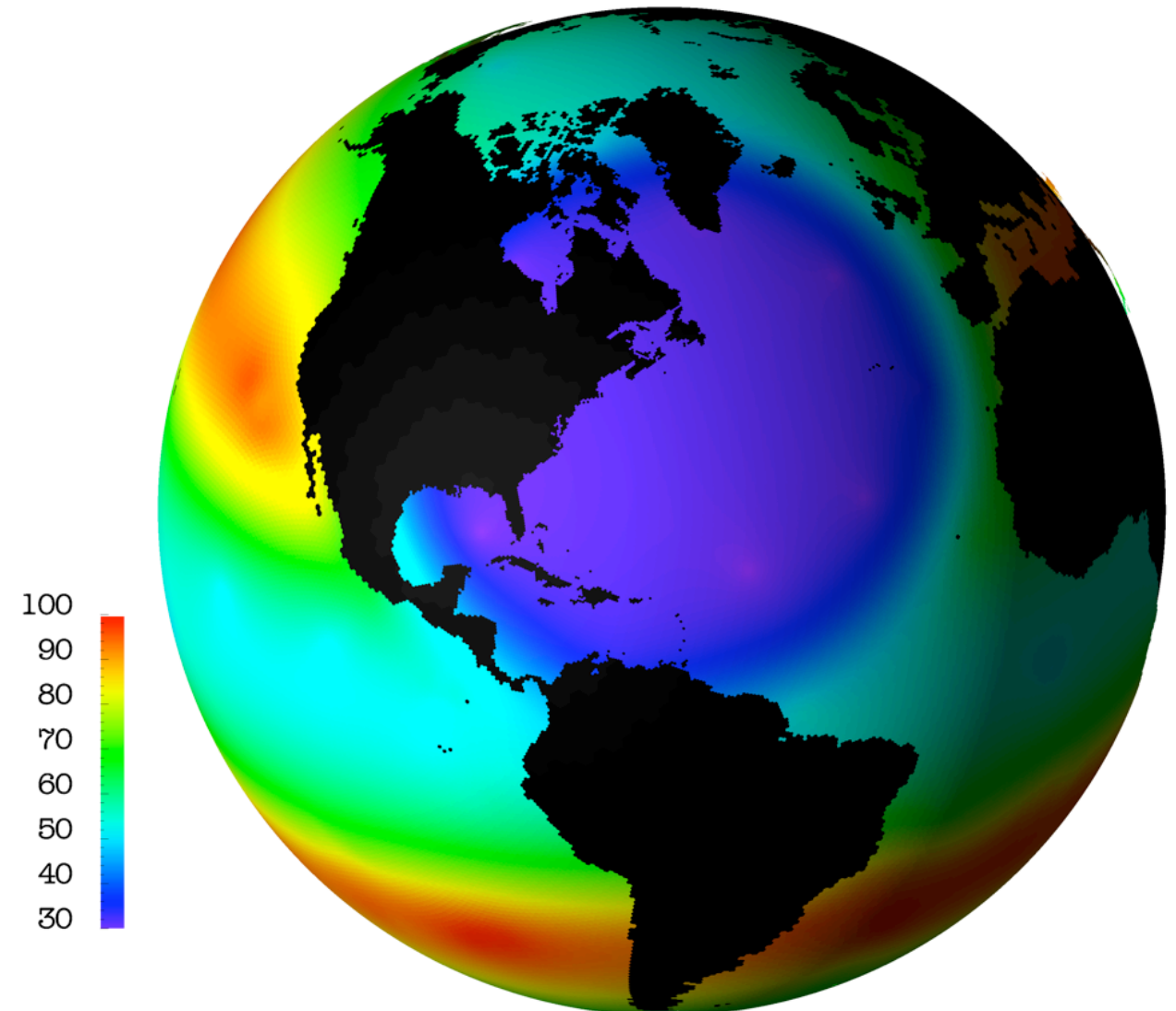ellipse shows region of mesh refinement.

Ocean simulations using SCVTs: R60km and R60kmNA

R60km: local grid resolution

R60kmNA: local grid resolution

R60km: total number of cells, 115K
equatorial and polar resolution: 40 km
subtropical resolution: 85 km

R60kmNA: total number of cells, 115K
equatorial and polar resolution: 50 km
subtropical resolution: 100 km
Gulf Stream - North Atlantic resolution: 30 km

Local grid resolution is defined as the average distance from a cell center to neighboring cell centers.

Description of SCVT MPAS Ocean Simulations

(Petersen, Maltrud and Ringler)

nominal 60 km horizontal resolution
z-level model, 40 levels (same as POP gx1v3)
topography taken from ETOPO, no smoothing
initial conditions for T and S from annual mean WOCE global climatology (Maltrud)
time-invariant wind stress forcing from annual mean NCEP 1958-2000 (Maltrud)

4th-order Runge-Kutta time stepping (dt=180 s for R60km, dt=120 s for R60kmNA)
3rd-order horizontal transport
2nd-order vertical transport
Jackett and McDougall EOS
vertical diffusivity/viscosity only a function of z

The simulations use (at the end of an ad hoc tuning exercise):
bi-harmonic dissipation on u and tracers at levels of 1e12 and 1e11, respectively
bi-harmonic dissipation scaled with (relative grid spacing)^4
anticipated potential vorticity method to dissipate enstrophy
restoring to WOCE annual mean T and S with 180 day time scale
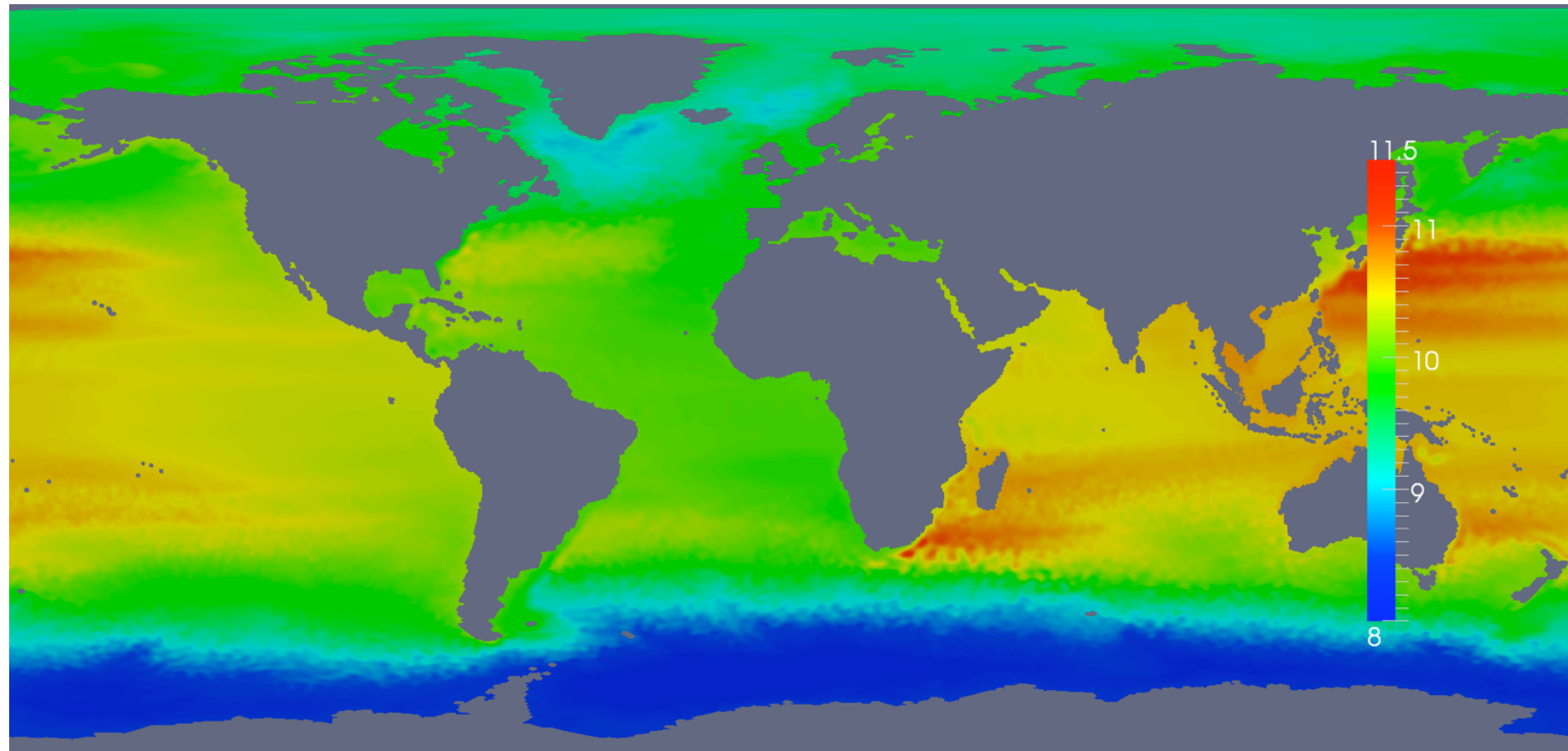
Comparison of R60km and R60kmNA

Figures to right show top layer thickness (h) at day 1600.

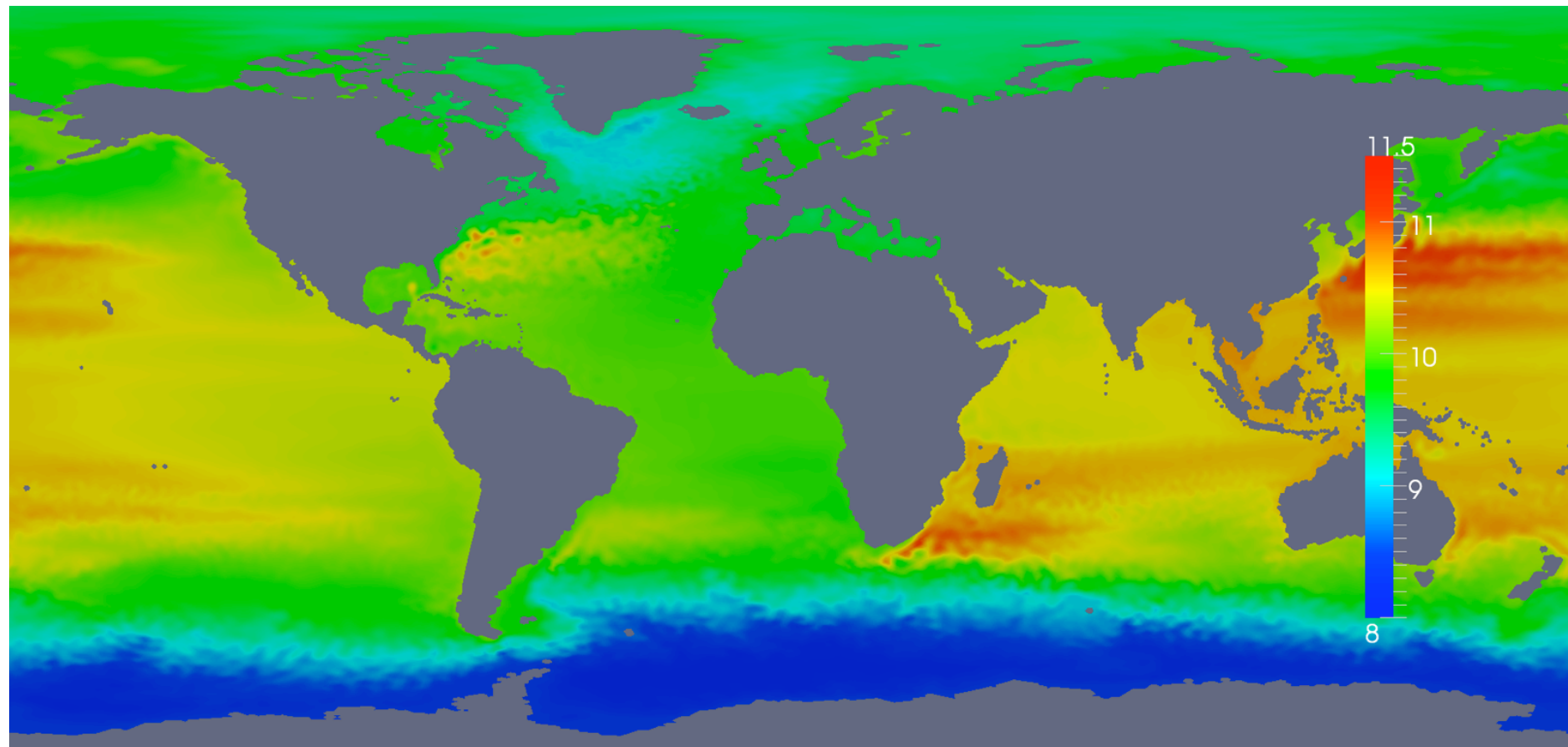SSH is derived as (h-10), with units of meters.

Both simulations show peak-to-peak amplitude of approximate 3.5 m.

The only notable differences are more structure in the Atlantic Ocean in R60kmNA and more structure in the Agulhas Current in R60km. In both case we attribute this to increased resolution.

R60km

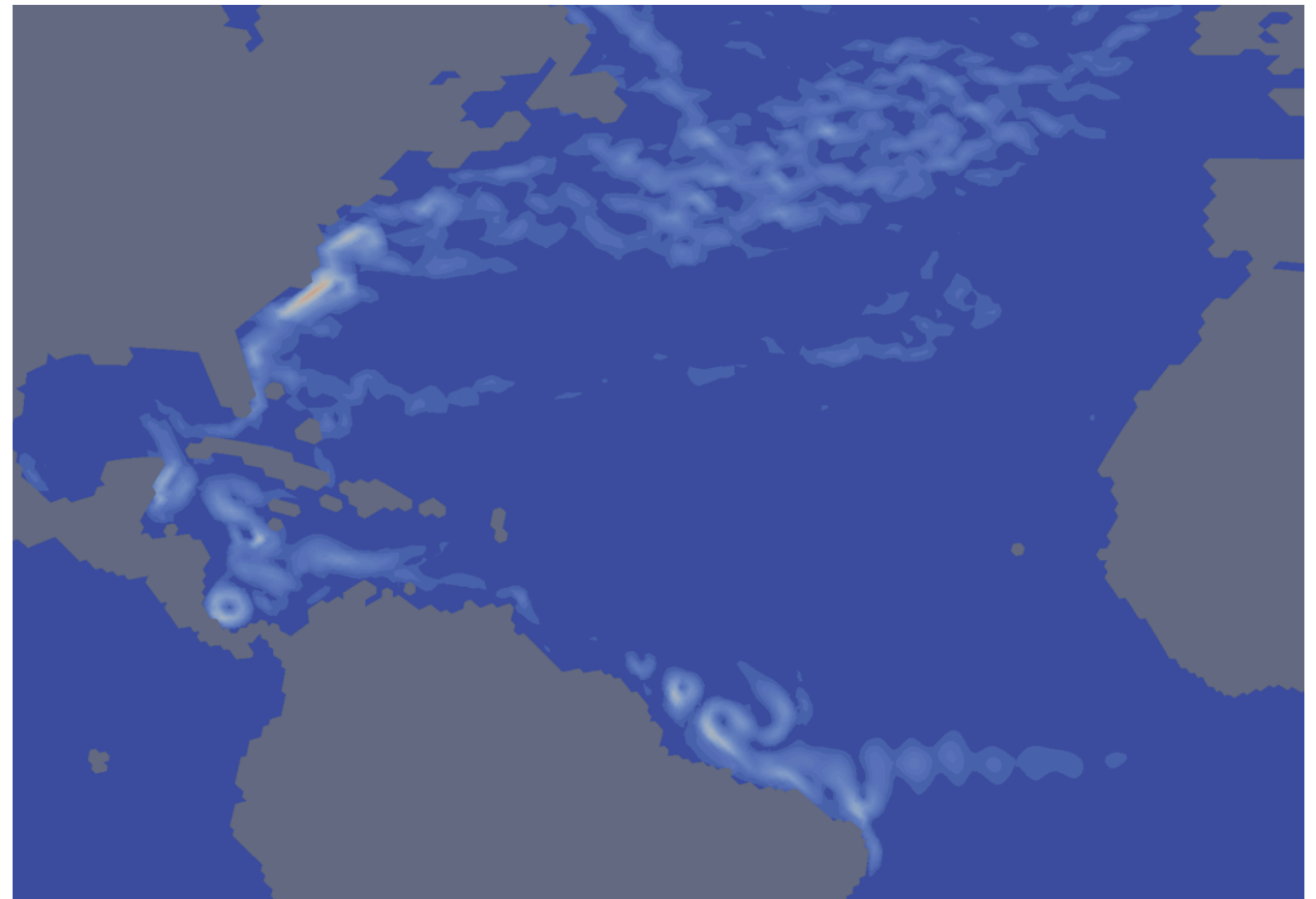R60kmNA

Comparison of R60km and R60kmNA

Figures to right show KE in top layer at day 1600. Both figures use same color scale with saturation (red) at velocity magnitudes of 1.0 m/s.

The model configuration is essentially equivalent, with the major difference being that the R60kmNA has 30 km resolution in the Atlantic whereas the R60km simulation has 80 km resolution.

As hoped, the enhanced resolution leads to notable improvements with respect to Gulf Stream separation, Gulf of Mexico Loop Current and overall level of eddy activity in the North Atlantic current.

As expected, 30 km is not sufficient for a fully-realistic simulation, e.g. we do not reproduce the Northwest Corner.

R60km

R60kmNA

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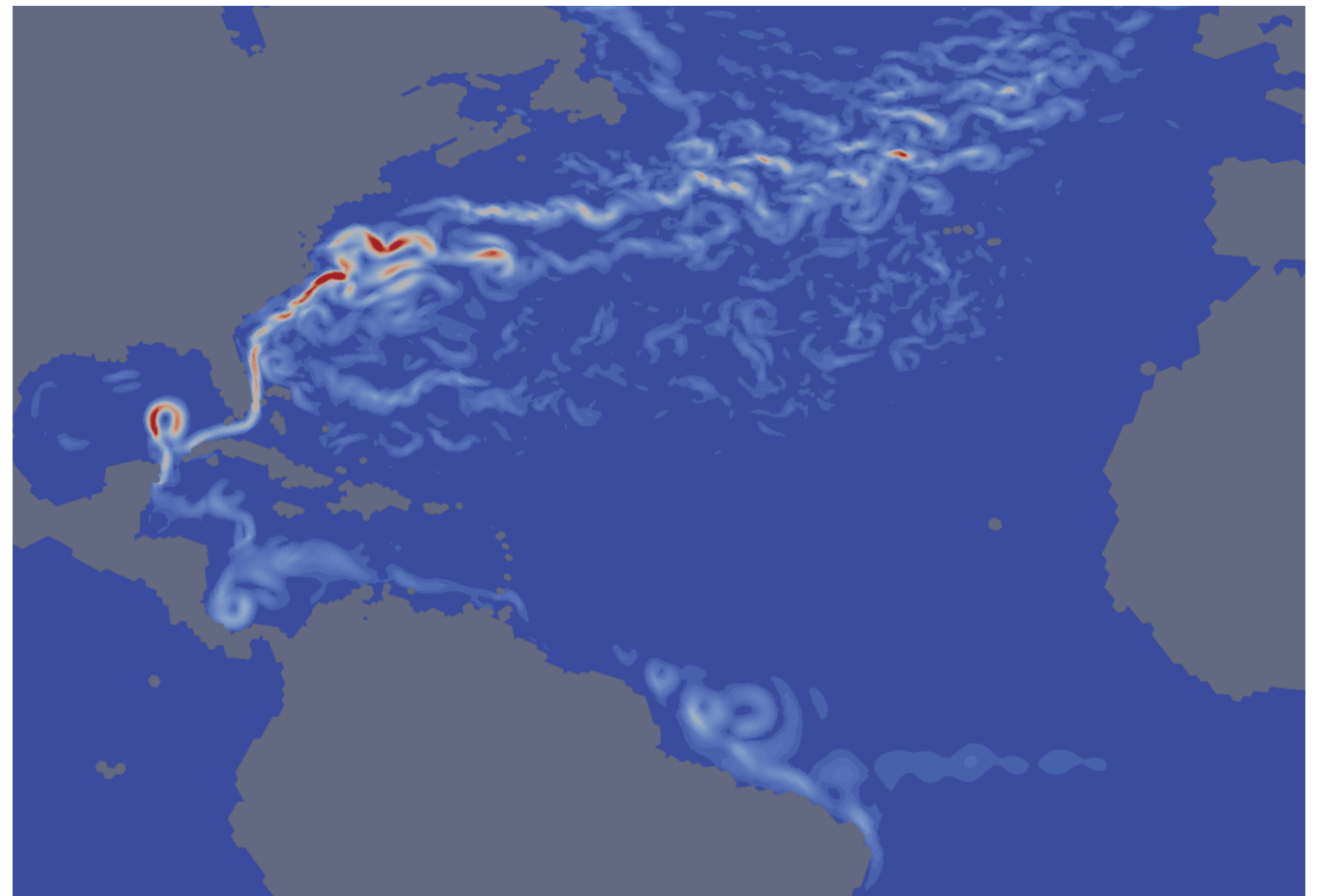
Time-series of KE in R60kmNA

Movie shows KE at one frame every 20 days for 1600 days.

Color saturates at the equivalent of 1.0 m/s velocity.

Note: The dissipation settings are changed about every 18 frames, i.e. about every 360 days on restart intervals. I did this as an ad hoc tuning exercise.

Frames 1-18: del2
Frame 19-36: del4
Frames 37-79: del4
    w/ lower value.

Download movie at http://public.lanl.gov/ringler/movies/R60kmNA.KE.mov (135 MB)

Summary

MPAS continues to show promise as a viable approach to both global uniform-resolution climate modeling and global-to-regional variable-resolution climate modeling.

I have begun to consider the notion that the variable-resolution MPAS approach *could* transform how we think about and how we use global climate models.

Our primary challenges moving forward are:
1. obtaining sufficient computational efficiency
2. developing scale-aware physical parameterizations

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